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Study of Neutron Scattering in the NIF Chamber and Use of Neutron Activation as a Yield Diagnostic

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ABSTRACT

One of the planned core neutron diagnostics for NIF will use material activation to aid in determining information about target neutron yields. While this technique was routinely used on Nova and is in use today on Omega, the substantially larger chamber size and neutron yields for NIF raise several new issues for this technique. The effect of neutron scattering, due to the larger amount of entrant equipment inside the chamber, and more importantly, scattering inside the NIF target itself, is shown to be a significant effect. The appropriate location of the counting room to analyze activated samples that is sufficiently protected from neutron fluences is discussed. There are no significant safety issues related to sample handling when using In and Cu for short durations (minutes). We recommend placement and thickness of Cu samples based on neutron yield.

1. INTRODUCTION

The primary mission of the neutron yield diagnostic (NYD) is to measure total deuterium-tritium (D-T) and/or deuterium-deuterium (D-D) fusion neutron yields of D-T and D-D filled capsules via the activation of Copper (Cu) and Indium (In), respectively. While this technique was routinely used on Nova and is in use on Omega, the substantially larger chamber size and neutron yields for NIF raise several new issues for this technique. The purpose of the these neutronics analyses is to provide relevant information to the neutron yield design team and the neutron diagnostic expert group to aid in the design of this diagnostic for NIF.

2. METHOD OF ANALYSES

A. Computer Codes

TART[1] was used to model the NIF chamber and its entrant equipment and transport neutrons to calculate neutron spectra and fluences in relevant zones, including in activation samples themselves. It was also used to calculate the emission spectra and dose rates from activated samples. TART is a three dimensional multi-group Monte Carlo neutron and photon transport code, which features a 566-group neutron and 701-point gamma cross-section structures. ACAB[2] was used to calculate nuclide generation and depletion/decay. The two codes are coupled in that neutron and photon path lengths calculated by TART are converted to fluences and used as input to ACAB to calculate the time dependent nuclide inventories.

B. NYD Operating Parameters, Computational Model, and Neutron Sources

To constrain our study, we have set operating limits on the NYD. We require a ratio of ^{62}Cu to ^{64}Cu counts during the 30 minute counting time to be greater than three. We initiate counting after 5 minutes for Cu and 30 minutes for In. The minimum inventory of ^{62}Cu and ^{115m}In at the start of counting must be

10^5 disintegrations per second. Sample dose rates must be less than 2.5 rem per hour when handled. We consider a yield range of 10^9 to 10^{19} for DT (Cu) and 10^9 to 10^{14} for DD (In). Finally, all samples are 5-cm in diameter and vary in thickness from 30 μm to 3 cm. The corresponding weights of these samples are 0.5 to 500 grams (Cu).

The 3-D TART model for the analyses includes all major entrant equipment: eleven Diagnostics Instrument Manipulators (DIM), two Static X-ray Imagers (SXI), one Target Positioner, one Neutron Pinhole (Pt), and four NYD entrant tubes. (See Figure 1.) This is expected to present a worst case scenario for in-chamber neutron scattering.

Calculations used either a mono-energetic source of neutrons (14.1 or 2.45 MeV) or the neutron spectrum emitted from a NIF target with a 9 MJ yield (~10^{16} neutrons). A DD spectrum was also used that was emitted from the same target where DD replaced the DT and was still driven with 1.8 MJ laser energy. These spectra were calculated using LASNEX[3]. Comparisons were made of the resultant chamber spectra using both sources.

C. Key Reactions

Neutron yields are expected up to 10^{19} per shots for 14.1 MeV D-T neutrons and to 10^{14} per shots for 2.45 MeV D-D neutrons. The neutron yields considered in the current calculations are 7×10^{14} (2 kJ) for Cu samples and a 10^{14} neutron yield (0.6 kJ shot) for In samples. After completing sets of activation calculations, linear scaling factors were applied to get the level of activation for appropriate levels of neutron yields. Cu and In are selected for their favorable threshold reactions for D-T and D-D neutrons, respectively. The ^{63}Cu(n,2n)^{62}Cu reaction has a threshold of 11 MeV and the ^{115}In (n,n')^{115m}In reaction threshold is 0.33 MeV

3. RESULTS

A. Comparison of neutron spectra from the two sources

The two neutron spectra (mono-energetic and LASNEX) were compared at various stand-off distances for a 'full' and 'empty' target chamber. The fraction of neutrons below 11.0 MeV is 8% with a mono-energetic source and 25% with the LASNEX spectra at 50 cm from chamber center. The contribution of the entrant equipment was seen to be quite small – only 3% more neutrons were below 11 MeV than for the 'empty' chamber case. (See Fig. 2 and 3). For the D-D neutron sources, the fractions below 0.33 MeV are 5% with a mono-energetic source and 20% with the LASNEX D-D source at 50 cm.

B. Spatial variations in neutron spectra and Sample activation using LASNEX spectra

The activation of copper samples were compared for four different port locations at a single stand-off distance and at various stand-off distances for a single port location. Our intent was to determine if there was any spatial variation in neutron spectra at the assigned ports for the NYD that could impact the accuracy of measurements. We also wanted to determine the inventory of ^{62}Cu and ^{64}Cu for a single sample size and yield at different stand-off distances. Scaling could then allow establishing locations for samples based on the expected yield and desired sample size. The sample activation was calculated using a 2 kJ DT-yield for Cu and a 10^{14} DD neutron yield for In. We found no significant difference in either copper or indium activation for samples placed with the same stand-off distance at different port locations. (See Table 1) The production of ^{62}Cu or ^{115m}In follows $1/r^2$ scaling as the stand-off distance increases. The ratio of nuclide production of ^{62}Cu and ^{64}Cu at different stand-off distances varies a factor of 4 from 50 cm to 400 cm stand-off distance. For Cu samples set outside the chamber shielding (550 cm) or outside the target bay wall (20 m), the ^{64}Cu production is substantially decreased, while the ^{62}Cu production only falls off as $1/r^2$. The largest ratio of ^{62}Cu/^{64}Cu is found at this farthest stand-off distance. We used only the LASNEX spectra for these results as we expected it more likely to discover spatial variations in spectra and to maximize the production of ^{64}Cu, creating a worst case scenario to provide some margin in our results.

C. DOSE RATE FOR CU AND IN SAMPLES

It will be necessary to handle the In or Cu samples after irradiation to transfer them to the detector counting chamber or to insert them into or take out of a carrying case. We assume that such actions will only take a minute and that this could be done perhaps 100 times in a single year. Samples will be sized and placed so as to become activated no greater than the NaI saturation limit, which is about 10^5 disintegrations per second for crystal sizes commonly in use for NYD today. We calculated the dose rate that a person transferring an activated sample (Cu or In) would be exposed to if the sample had this quantity (Ci) of the key nuclide. We used the 400-cm stand-off LASNEX spectra and assumed 50 shots took place with the same Cu and In samples, spaced 24 hours apart for conservatism. The dose rate for the samples when activated to the detector saturation limit is 0.003 rem/hr for Cu and 0.12 rem/hr for the In. sample. (See Table 2). The main contributor for the Cu is the ^{62}Cu while ^{116m}In is the major contributor for In. Both samples would be safe to handle for short durations.

D. Recommended sample thickness, standoff distance by neutron yield

For the operating criteria outlined earlier in this paper, we have set locations and Cu sample thicknesses to be able to measure certain yields. (See Table 3). The stand-by times before counting is 5 minutes for Cu samples and the minimum required counting level for ^{62}Cu is 10^5 disintegrations per second. The total accumulated counts for Cu samples were calculated for a 30 minute counting time to examine the accumulated ^{62}Cu and ^{64}Cu production ratio. In all cases the ^{62}Cu/^{64}Cu ratio is larger than the required limit of three. For neutron yields up to 10^{14}, the copper must be <u>inside</u> the chamber to have sufficient activity induced. At 10^{15} neutron yield, the sample could be placed outside the chamber shielding (550 cm radius) and at 10^{16} – 10^{19} neutron yields, the sample could be positioned outside the target bay wall (20 m). The exterior chamber locations are desirable since mechanical systems would be much simplified and access to the sample easier than for in-chamber positioning after yields of this magnitude.

E. NYD counting room

The counting room could be located on the first floor of the diagnostic building. Since this is outside the target bay wall and below the –3'6" level floor, the actual concrete shielding thickness to the counting room would be more than 5 m, providing an attenuation factor of more than 10^{15} for neutrons. Scaling from conditions measured at Omega for NaI crystal neutron activation, there should be no need for special shielding requirements for a NIF counting room beyond standard NaI detector shielding.

F. Conclusions

The neutron scattering in the fuel region for yields at and above ignition causes substantial softening of DT and DD spectra below threshold energies, more than 10% for a 10 MJ yield. If the degree of scattering is not consistent shot to shot for the same yield, this would introduce uncertainty in the measurement. Entrant equipment inside the chamber appears to have only a modest impact on chamber neutron spectra, contributing an additional 3% to neutrons below the Cu or In threshold. NYD Cu samples can be placed exterior to the chamber for neutron yields above 10^{15}.and outside the target bay wall at 10^{16} neutrons. The dose rates from samples activated to an inventory of 10^5 disintegrations per second (Cu or In), which we take to be the saturation limit for NaI counting for the Cu, is acceptably low such that no special precautions are required for short duration handling. If the NYD counting room is located on the diagnostic building first floor, the thick concrete target bay wall should ensure no special shielding should be required beyond standard detector shielding.

Acknowledgments

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References

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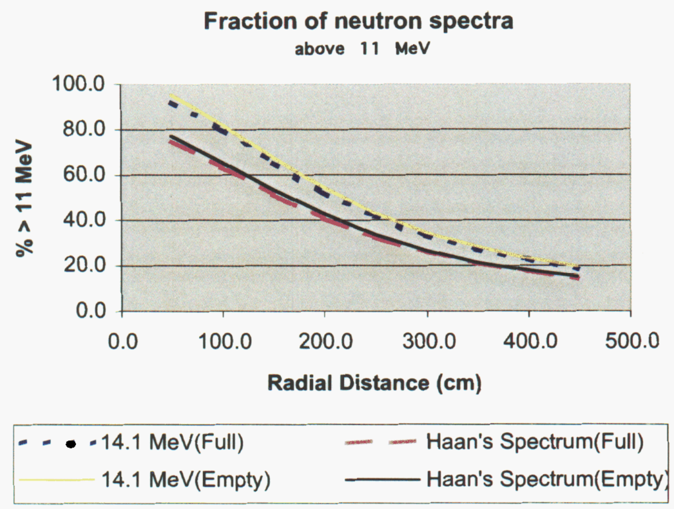

Fig. 3. Fraction of neutron spectra above 11 MeV at various stand-off distances with scattered and mono-energetic neutron source with and w/o entrant equipment

	r=50,a	r=50,c	r=100	r=125	r=250	r=400	r=550	r=2000
CU-62	2.01E+07	2.00E+07	5.04E+06	3.23E+06	8.49E+05	3.39E+05	1.60E+05	1.05E+04
CU-64	2.73E+05	2.73E+05	7.97E+04	6.28E+04	2.45E+04	1.89E+04	2.55E+03	1.38E+02
Cu62/Cu64	7.36E+01	7.34E+01	6.33E+01	5.15E+01	3.46E+01	1.79E+01	6.26E+01	7.64E+01

t = 0, Units are Disintegration/sec
Sample locations (a, b, c, d) are at four different ports, (18,304), (77,174), (102.5,335.62), and (161, 146)
R=550 (outside chamber), R=2000 (outside baywall, switchboard area)

Table 1. ^{62}Cu and ^{64}Cu activation at various stand-off distances

	Cu-62	Cu-64	Ni-65	Total(mrem/hr)
Nuclide	9.99E+04	1.13E+04	2.20E+02	
dose rate	2.48E+00	5.54E-02	1.23E-03	2.53E+00

Nuclide	IN-113M	IN-114	In-114m	IN-115m	IN-116m	Total(mrem/hr)
dis/sec	1.38E+04	3.65E-01	3.03E+02	9.99E+04	4.02E+06	
dose rate	5.28E-02	1.29E-08	4.30E-04	2.30E-01	1.19E+02	1.19E+02

Table. 2. Total Dose Rate for samples activated to detection limit, 10^5 dis/sec for ^{62}Cu and ^{115m}In

	Stand-Off (cm)	Sample Thickness (mm)	Neutron Yield
Inside	50	10	1.0E+13
Chamber	250	20	1.0E+15
Outside	550	11	1.0E+15
Chamber	2000	17 - 0.025	1.0E+16 - 1.0E+19

Table. 3. Allowable sample thickness at various stand-off distances and yields

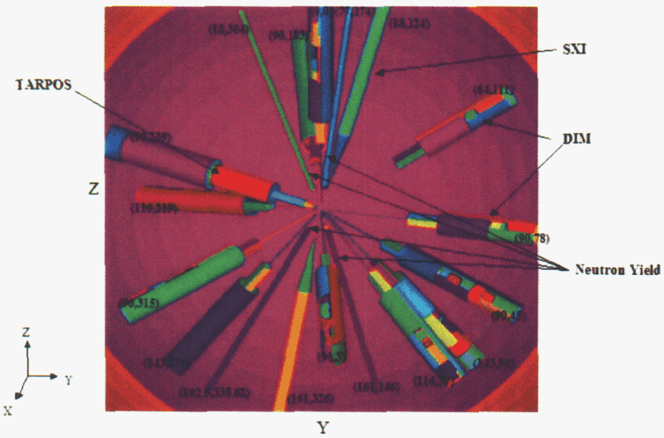

Fig.1. 3-D Tart Model of NIF chamber including all major entrant equipments

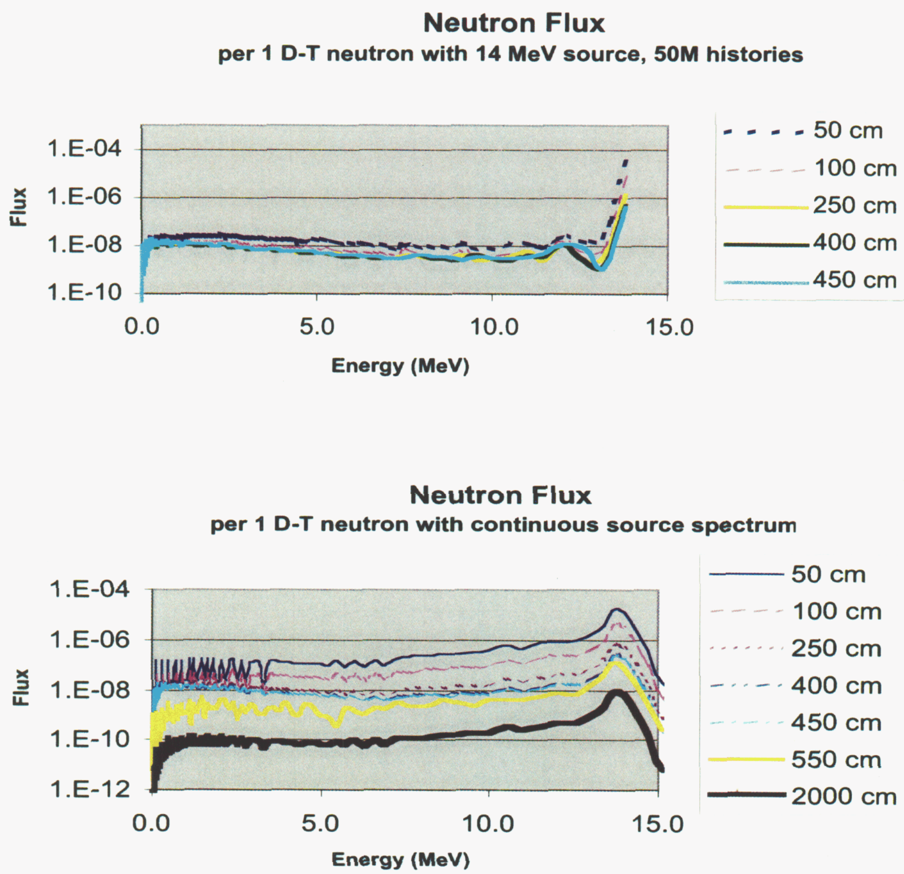

Fig. 2. Two neutron spectra generated by 14.1 MeV and Haan's Spectra neutron source